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Comparative Effect of Lime-Sulfur and Flotation Sulfur on Tree Growth and Fruit Yield

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Comparative Effect of Lime-Sulfur and Flotation Sulfur on Tree Growth and Fruit Yield

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INTRODUCTION

Liquid lime-sulfur and flotation sulfur are both widely used as fungicides on apples in Virginia. The dry, wettable sulfurs are also extensively used and to a considerable extent the remarks made about flotation sulfur can be considered as applying to these materials. The dry materials vary considerably in their physical characteristics, however, and the selection of a single product satisfactorily representative of all would not be possible. Flotation sulfur is the most widely utilized elemental sulfur in Virginia and experience has shown it to be the most generally satisfactory of these as a fungicide in apple scab control. For these reasons, flotation sulfur was selected for parallel comparison with the standard sulfur fungicide, liquid lime-sulfur.

The grower has long been aware of some of the more obvious injurious effects of liquid lime-sulfur, principally those effects apparent as scorching, burning and dwarfing of the foliage, and he has sought to avoid such injury by the substitution of milder materials, restricting the use of lime-sulfur to a necessary minimum number of applications, and by reducing the strength of the spray solution. These practices have proved helpful but have not afforded a complete solution. Experience generally has confirmed the observation that better foliage develops on trees on which the use of lime-sulfur is avoided entirely.

It is entirely reasonable to expect differences in abundance and condition of foliage to be reflected in differences in tree growth and fruit yield in view of the role of the leaf as the food manufacturing structure of a plant. Any treatment which impairs either the condition or function of leaves should, therefore, reduce the growth of the tree and yield of fruit. The experiments reported here were designed to yield information on this relationship. A review of the more relevant results of investigators reporting information gained on the same and related phases of this problem is included in the discussion.

PLAN OF EXPERIMENT

A block of approximately 200 eight-year-old Starking Delicious apple trees on the R. S. Smith farm near Winchester was selected in 1941, to be employed in the tests for five years. The block consisted of seven rows of trees, with thirty tree locations per row, but with a few vacancies. The land in the test area was reasonably uniform in type and nearly level, with a maximum elevation differential of about 12 feet. The trees, growing in a heavy, fertile limestone soil, were in a vigorous growing condition and had fruited but lightly at the beginning of the experiment.

The trees in the first and succeeding odd numbered rows were selected to receive the lime-sulfur treatment, and those in the second and succeeding even numbered rows selected to be sprayed with flotation sulfur. Separate treatments began with the first fungicidal or pre-pink spray and were continued through the first cover application. The rows receiving flotation sulfur were sprayed with it through the second cover, those receiving lime-sulfur were sprayed with lime-

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sulfur through the first cover but received Bordeaux mixture in the second cover spray. Bordeaux mixture was applied uniformly over the entire block in the third and subsequent covers. The two sulfur materials were utilized thus because such schedules represent the most satisfactory schedule, judged on the basis of general experience. There seemed to be no justification for projecting the use of either material beyond its normal season for the sake of an experiment when experience had demonstrated that the sulfur fungicides are unsatisfactory for use as a midsummer cover spray in Virginia.

Lime-sulfur was used at the rate of 8 quarts per 100 gallons of spray with 3 pounds of lead arsenate and 4 pounds of spray lime being added in the petal-fall and first cover sprays. Flotation sulfur paste was used at 12 pounds per 100 gallons of spray except in 1941 and 1942 when 6 pounds of the then available dry wettable flotation was used. Three pounds of lead arsenate and 4 pounds of spray lime were used with the flotation sulfur in the post-blossom sprays. A 2-4-100 Bordeaux mixture was used in all late cover sprays.

The circumference of the trunks of all trees was recorded and the point of measurement marked at the beginning of the 1941 season. Measurements to determine the annual growth increase were made in November, 1941, and each year following through 1945.

Yield records were taken on the basis of bushel field crates per tree except in 1941 when because of the light crop the fruits were counted and weighed. The yield records for each year are presented separately; the growth increase as a five-year summary. Tree growth comparisons are made on the basis of 26 pairs of trees selected in 1941, selection being made on the basis of equal trunk measurements at the time. The same pairs were not utilized in the yield comparisons because of variation in frost injury from the upper to the lower end of the experimental block.

RESULTS

Fruit Yield in 1941.—The young trees were still in a strongly vegetative phase in 1941 and set only a very light crop of fruit. The apples were counted and weighed at harvest time, but the records were too erratic to prove of value. Differences were recorded but did not prove statistically significant. There was no difference in fruit finish and size from the two treatments.

Fruit Yield in 1942.—The trees set a sufficiently heavy crop in 1942 to provide good yield data. Records were secured from the first four rows of trees, fifty-two trees of comparable size from each treatment being available for comparison. These were grouped into twenty-six sets of two adjacent trees within each treatment. These twenty-six sets of two were then paired between treatments, pairing being on a basis of proximity of the sets. The yield records and statistical evaluation of the differences are given in Table 1. These reveal that the 52 trees sprayed with flotation sulfur yielded 173 crates of fruit as compared with 87 crates from the same number of lime-sulfur sprayed trees. The average yield of 3.33 bushels per flotation sprayed tree was almost twice the 1.68 bushel average of the lime-sulfur sprayed trees. The difference is highly significant, the calculated sample value of t greatly exceeding the minimum significant value at the 1 percent level.

Fruit Yield in 1943.—Yield records in 1943 were based on 78 trees for each treatment and these were grouped into sets of three trees each for purposes of statistical computations. Pairing of the sets was again on the basis of proximate location because variation in frost injury from the upper to lower part of the orchard would have rendered any other pairing unacceptable. Differences

Table 1.—Lime-sulfur versus flotation sulfur in spray treatments on Delicious apple. Comparison of annual yield records expressed in terms of bushel field crates

Pair number	1942		1943		1944		1945	
	Lime-sulfur	Flotation sulfur	Lime-sulfur	Flotation sulfur	Lime-sulfur	Flotation sulfur	Lime-sulfur	Flotation sulfur
1	1	4	19	17	29	18	36	39
2	7	8	13	19	19	44	14	28
3	2	6	11	15	13	42	21	29
4	3	10	7	9	20	30	20	21
5	2	10	2	2	23	21	21	7
6	2	1	1	2	50	46	13	8
7	3	4	4	5	32	23	24	11
8	5	11	3	6	12	41	18	21
9	6	6	7	22	28	29	16	18
10	2	13	3	14	16	35	24	46
11	1	3	6	7	18	17	21	25
12	2	4	5	13	21	17	18	17
13	3	5	2	12	20	17	21	31
14	8	8	7	12	28	31	12	11
15	4	11	3	3	26	35	10	11
16	2	2	7	14	20	23	11	21
17	6	4	8	3	18	17	12	20
18	5	4	1	16	22	32	10	21
19	5	6	4	12	18	23	34	33
20	5	13	2	15	13	19	18	25
21	2	9	6	16	12	19	10	28
22	2	8	11	13	15	23	13	26
23	3	11	3	13	18	13	8	30
24	3	8	7	9	19	27	22	10
25	1	3	2	17	7	11	27	22
26	2	1	5	12	11	25	6	26
Total	87	173	149	303	528	678	460	585
Mean	3.35	6.65	5.73	11.65	20.31	26.08	17.70	22.50
Sample value of t	4.176		4.501		2.983		2.376	
Significant value of t at 5% and 25 degrees of freedom	2.060		2.060		2.060		2.060	
Significant value of t at 1% and 25 degrees of freedom	2.787		2.787		2.787		2.787	

in yield were again significantly greater on the trees sprayed with flotation sulfur, the 78 flotation sprayed trees yielding 303 crates of fruit, as compared with 149 for the opposite and equal number of lime-sulfur sprayed trees. The yield per tree of the flotation sprayed trees was 3.88 bushels against 1.91 bushels for those receiving lime-sulfur. The difference in favor of the flotation treatment was again highly significant, the computed sample value of t being almost twice the significant value at the 1 percent level.

A previously unnoticed difference in abundance of fruit buds on the two treatments became apparent as the buds opened. Those trees which had received flotation sulfur in 1941 and 1942 carried a much heavier set of fruit buds than those which had received lime-sulfur. The difference was so striking that color photographs were made at full bloom and one of these is presented as Plate I. Differences in yield in 1943 were no doubt partly attributable to this difference in abundance of bloom. The probable cause of this development would seem to lie in the depressing effect of lime-sulfur upon the photosynthetic activity of sprayed leaves at a critical time in bud differentiation and formation. Experimental observations upon this effect are more fully explored in the general discussion.

Fruit Yield in 1944.—The pairing of sets of three trees, begun in 1943, was continued through 1944 and 1945. The trees sprayed with flotation sulfur again outyielded those receiving lime-sulfur, the figures being 678 crates of fruit from the trees sprayed with flotation sulfur, as compared with 528 crates from the

Plate I.—Photograph illustrating the difference in abundance of bloom on lime-sulfur and flotation sulfur treatments in 1943. Right, row sprayed with lime-sulfur two previous years; left, row receiving flotation sulfur during the same period. Note heavier bloom on trees sprayed with flotation sulfur.

same number of trees receiving lime-sulfur, or 8.69 bushels against 6.77 bushels on a single tree basis. The difference between treatments was again significant at the 1 percent level, although the difference was not as great as in the two previous years. Differences in abundance of fruit buds were conspicuous only in the lower part of the orchard in 1944.

Fruit Yield in 1945.—The trees sprayed with flotation sulfur again outyielded those receiving lime-sulfur, the yields being 585 bushels for the flotation sulfur treatment as compared to 460 for lime-sulfur, or 7.50 bushels versus 5.90 bushels on a single tree basis. The difference was significant at the 5 percent level but not at the 1 percent level. The results in 1945 were complicated by a freeze which occurred over a month after full bloom and at which time the fruit was about one-half inch in diameter. An earlier frost had already reduced the number of surviving buds considerably. The comparatively high yield was a reflection of the excellent growing weather which prevailed throughout the summer, large fruits being produced on all trees.

SUMMARY OF FOUR YEARS' RESULTS ON FRUIT YIELDS AND TREE GROWTH

For four consecutive years young bearing Starking Delicious apple trees receiving flotation sulfur in the first five sprays significantly outyielded those in parallel rows which were sprayed with liquid lime-sulfur in the first four sprays. The average annual yield per tree was 5.85 bushels for trees sprayed with flotation sulfur and 4.06 bushels for those sprayed with lime-sulfur. A statistical com-

parison of the yield records over the four years was made on the basis of single tree comparisons, pairing being made between trees directly opposite each other and omitting those paired against vacant locations, weak trees, etc. This method had the disadvantage of pairing many trees of unequal size although the lack of balance did not favor either treatment. A total of 281 pairings were made over the four years. The results indicated the greater yield from trees receiving flotation sulfur to be highly significant and not due to chance. The computed sample value for t (square root conversions) in these comparisons was 6.55 which compares with significant values of 1.97 at the 5 percent level and 2.60 at the 1 percent level.

Scab control was equal and excellent on both treatments in all years.

The trunk girth measurement was recorded for all trees at the beginning of the experiment and the point of measurement marked with paint to insure subsequent measurements being made at the same point. Measurements were made in April and November in 1941, and in November of each succeeding year through 1945. Measurements were made at a point one foot above the ground line; obviously weak or damaged trees were not measured.

The first and outside row was next to a shallow highway drainage ditch and the trees in this row were larger than the average of those on the inside rows. No effort was made to compensate for any border effect. Trees of near equal size were paired for the five-year comparison, however. A total of twenty-six pairs were selected for comparison and the data are given in Table 2.

Although the trees sprayed with flotation sulfur made a slightly greater growth increase, the difference did not prove to be statistically significant. This

Table 2.—Lime-sulfur versus flotation sulfur in spray treatments on Delicious apple. Summary of five-year trunk girth increase measurements

Pair number	Increase	
	Lime-sulfur	Flotation sulfur
	Inches	*Inches*
1	9.50	10.75
2	13.25	12.75
3	9.75	11.75
4	10.00	12.50
5	9.75	8.50
6	10.50	10.88
7	10.75	11.00
8	11.00	12.38
9	11.00	12.50
10	12.00	11.25
11	12.50	12.75
12	12.25	12.75
13	11.00	11.75
14	11.00	11.75
15	11.75	11.25
16	12.50	11.25
17	10.00	12.50
18	9.75	9.50
19	11.50	12.25
20	11.75	10.75
21	8.00	9.50
22	9.75	11.50
23	10.75	10.00
24	11.75	10.75
25	12.00	11.00
26	11.50	10.13
Total	285.25	293.64
Mean	10.97	11.29
Sample value of t	1.577	
Significant value of t at 5% and 25 degrees of freedom	2.060	

development was not unexpected as the trees were in a vigorous state of growth throughout the experiment, and the different treatments did not cover the major growth period but extended only into the earlier part of the growing season after which treatments became uniform.

DISCUSSION AND REVIEW OF LITERATURE

Several investigators have reported upon similar and related phases of the problem dealt with here, that of the effect of sulfur fungicides upon the growth and fruiting of the apple tree. No attempt has been made to present a comprehensive review of such work here but rather to include only those references which seem pertinent.

Direct comparisons between lime-sulfur and other materials have been made by several investigators for the purpose of determining possible effects upon tree growth and fruit yield. Dutton (8) in reporting yield records for five years of a seven-year orchard comparison between lime-sulfur and a non-toxic fungicide (not indentified) on Baldwin apples stated that the trees which received the non-toxic material yielded an average of 645 pounds of fruit per tree against an average of 341 pounds for those receiving lime-sulfur. He concluded that there was "a definite falling off in production where unsafe combinations were used over a period of several years." Dutton (9) also reported that lime-sulfur reduced the fruit set on Baldwin in tests where spraying was from the inside to outside as well as from the outside. The injury was reflected in a seriously reduced crop during the two succeeding seasons. In another test on trees of the Jonathan and Hubbardston apple varieties, lime-sulfur sharply reduced the number of blossom buds on spurs. A like reduction in blossom bud development in the experiment here reported is illustrated in Plate I.

Mills (20) reported that trees which received lime-sulfur through the petal-fall spray followed by wettable sulfur over a four-year period increased their average rate of yield by 3.4 to 3.6 bushels per tree, whereas those receiving the standard all lime-sulfur schedule increased their average yield by only 2.4 bushels per tree. Trees receiving wettable sulfur all season increased their rate of yield by 5.4 to 5.9 bushels per tree. On the basis of bushels per acre, with lime-sulfur all season as the standard, the trees receiving lime-sulfur through the calyx spray followed by wettable sulfur showed an annual increase of 38 bushels per acre over the standard; those receiving wettable sulfur all season showed an annual increase of over 100 bushels per acre over the standard.

Christopher (7) in comparing lime-sulfur and flotation sulfur concluded that "The trend seems toward reducing yield (with lime-sulfur) but sufficient data to make a general statement are not available." A more marked trend toward yield reduction following the use of lime-sulfur was apparent with the Rhode Island Greening variety, however.

Burrell (4) compared lime-sulfur and flotation sulfur in four schedules on young McIntosh and found that trees sprayed with lime-sulfur in an all-season schedule yielded only about two-thirds as much as trees sprayed with flotation sulfur all season. Reductions were less in split schedules. Fruit finish, terminal growth, and trunk development were about the same with all materials.

Folsom (10) found the effect of spray treatments on tree growth to be cumulative and not pronounced in two or three years. Christopher (6) tested a number of sulfur dust and spray treatments on young trees, beginning with one-year whips, and on McIntosh found only those receiving sulfur dust to have made significantly more growth than those receiving lime-sulfur 1 to 50. Both sulfur dust and lime-sulfur 1 to 100 were better than lime-sulfur 1 to 50 on

Baldwin. In another publication Christopher (7) in reporting on a comparison between lime-sulfur and flotation sulfur on older trees concluded that the results indicated a marked superiority of flotation sulfur from several points of view and stated that "lime-sulfur resulted in a greater reduction of carbon dioxide assimilation, less stored starch, more visible leaf injury, less tree growth and a smaller yield."

Perhaps the most important fact relative to the behavior of lime-sulfur to be established in recent years is that liquid lime-sulfur spray applications markedly depress the photosynthetic activity of apple foliage for several days following an application. Since food manufacture is the primary role of a leaf it seems reasonable to assume that any appreciable impairment of this function would be reflected in growth, bud formation, fruit set, yield, or any other related development.

Hoffman (15), utilizing apparatus developed by Heinicke and Hoffman (14) found that lime-sulfur 1 to 40 reduced carbon dioxide assimilation an average of 37 percent in over 100 determinations. Christopher (5) reported that flotation sulfur also reduced carbon dioxide assimilation but to a lesser degree than that reported by Hoffman for lime-sulfur. In a later report Christopher (7) reported that lime-sulfur reduced carbon dioxide assimilation to about 66 percent of normal following a spray. This compared with a reduction to 84 percent for flotation sulfur 16 pounds to 100 gallons. Heinicke (13) studied the effect of lime-sulfur applications upon the photosynthetic activity of an entire tree and reported that lime-sulfur 1 to 40 reduced the rate to about half of normal for 5 days. The tree had fully recovered in 15 days and the reaction to a second spray at that time was less severe. He calculated the loss in dry matter from the reduction in photosynthetic activity from one spray application made to the tree under study to be equal to that in one-half bushel of apples. The sprays were applied in July.

Brody and Childers (3) checked the effect of higher dilutions of lime-sulfur to determine their safety in comparison with the standard 1 to 40 dilution. Dilutions of 1 to 40, 1 to 80, 1 to 100, and 1 to 125 were used. They did not find the higher dilutions to be less injurious and stated "(From this brief report) it is apparent that the dilute liquid lime-sulfur sprays may cause marked reductions in the apparent rate of photosynthesis of Stayman apples for a period of from 3 to 5 days after spray treatment, even though no visible burning occurs." Hoffman (16) found that the reduction in photosynthetic activity resulting from lime-sulfur applications was much greater at high than at more moderate temperatures.

The elemental sulfurs also depress the photosynthetic activity of foliage sprayed with them, but to a lesser degree than does lime-sulfur. Hyre (19) in reporting upon several such materials stated that flotation sulfur paste (Koppers) gave the least reduction in photosynthetic activity and lime-sulfur the greatest. Differences between wettable sulfurs were not significant except in one instance; all but this one gave significantly less reduction than did liquid lime-sulfur. Agnew and Childers (1) studied the effect of two mild sulfur sprays upon photosynthetic activity of apple leaves and found little difference except under high temperature conditions. They concluded that "From these results and those of other workers it is clearly evident that sprays which contain sulfur in suspension have less effect upon photosynthesis of apple leaves than sprays which contain sulphur in solution." Christopher (7) in comparing lime-sulfur and flotation sulfur stated that " . . . the lime sulfur application reduced carbon dioxide assimilation about twice as much as did the very heavy application of flotation sulfur." In an

earlier report Christopher (5) in reporting upon the effect of flotation sulfur upon carbon dioxide assimilation reported its depressing effect to be less serious than that reported for lime-sulfur.

The possibility that what was being interpreted as a decrease in the rate of carbon dioxide assimilation might actually be an increase in respirational activity induced by the spray application was investigated by Hoffman (17) who summarized his findings with the statement that ". . . it seems from the data at hand that one is justified in concluding that lime-sulphur injury to apple leaves is largely due to a decrease in the rate of photosynthesis rather than an increase in the rate of respiration."

The depressing effect of lime-sulfur on the photosynthetic activity of apple foliage has generally been considered to be of a transitory nature, a conclusion supported by the results of several investigators. That injury may, under some circumstances, persist much longer through modification of leaf structure is suggested by the work of Pickett and Birkeland (21). The internally exposed surface of a leaf is one of the factors which affect the rate of photosynthesis. These workers sprayed apple foliage with lime-sulfur 1 to 40 plus lead arsenate 4 pounds per 100 gallons, at weekly intervals for six applications and followed these with additional sprays of lead arsenate alone and lead arsenate and summer oil. They found that the treatment significantly reduced the depth of the palisade tissue, the diameter of lower palisade cells and the number of cells per unit area. The thickness of the leaves was also affected. They concluded that "It seems justifiable, therefore, to conclude that part of the reduction in photosynthetic activity resulting from repeated applications of certain spray materials may be due to the changes brought about in the internal structure of the leaves."

A reduction in photosynthetic activity must inevitably be reflected in the amount of stored food. Christopher (7) in examining the pith area of apple twig terminal growth found only 13 percent of the cells to be filled with starch grains where lime-sulfur had been used as a spray, whereas 32 percent of the cells were starch filled from those sprayed with flotation sulfur. A possible relationship between this difference in amount of stored starch and fruit bud formation is suggested by the work of Haller and Magness (11) who found that a condition of high carbohydrate concentration is apparently necessary for the formation of blossom buds. Harley et al. (12) demonstrated that certain varieties, including the Delicious, differentiate fruit buds early and therefore respond to early season influences which affect the supply of carbohydrates.

The reduction in the number of fruit buds formed and the number of normal blossoms set appears to be a reasonable consequence of lowered photosynthetic activity. Observations made in these investigations, particularly in 1943, indicate a marked influence of spray treatment on fruit bud formation. Dutton (9) reported that 51 percent of the spurs of Jonathan receiving a non-toxic spray formed blossom buds, whereas only 14 percent of those receiving lime-sulfur formed fruit buds. Figures for the Hubbardston variety in the same test were 48 and 22 percent, respectively.

Lime-sulfur has been frequently credited with reducing the set of apples. Only a few years after lime-sulfur was first used as a summer fungicide, Sanders (22) stated that growers reported that they "Sprayed the apples off the trees with lime and sulfur." He conducted orchard experiments with different dilutions of lime-sulfur and in various combinations. As a result of these studies he stated that "It will be noted from the table that in all cases the trees sprayed with even the most dilute (1-75) solutions of lime-sulfur gave fewer apples than the unsprayed trees." He further concluded from his experiments that lime-sulfur

caused its greatest injury when applied about two weeks after blossom, a conviction widely shared and frequently expressed by others. He stated that lime-sulfur caused little damage before bloom, possibly a little harm after bloom.

The term "sulfur shock" is frequently met with in discussions of the effect of lime-sulfur upon fruit set. The term is generally used in a manner which seems to imply a direct effect upon the fruit rather than indirectly through influence upon photosynthesis and food accumulation. However, no evidence has come to the writer's attention which would seem to establish the existence of such a "shock" reaction apart from the well-established effect of lime-sulfur upon photosynthesis and its indirect effect upon fruit set.

Bagenal et al. (2) reported that lime-sulfur 1 to 29 caused an excessive fruit drop. Howlett and May (18) reported that lime-sulfur 1 to 40 and 1 to 60 caused some abscission of fruit from Ensee and Grimes Golden, although they did not consider the drop great enough to reduce the crop commercially on these varieties. They felt that the commonly held impression that the second after-bloom spray was the most likely to cause fruit dropping was frequently a misinterpretation of facts, for the second post-bloom spray is normally applied shortly before the June drop and the drop which follows would, in large measure, have occurred anyway. The Delicious differs from the varieties these workers worked with in that it tends to have an early heavy drop and a light late drop, whereas the opposite holds for the Grimes and Ensee varieties.

SUMMARY AND CONCLUSIONS

Young bearing Starking Delicious apple trees were sprayed with liquid lime-sulfur and flotation sulfur over a period of five years to determine the effect of the two materials on fruit yield and tree growth. Differences in treatment began with the pre-pink spray and extended through the second cover spray, a usage which conforms with general spray practice. The trees receiving flotation sulfur significantly outyielded those receiving lime-sulfur in the four years that a crop was borne. Differences in trunk girth increases between treatments were not significant.

Differences in yield were brought about by a heavier set of fruit on the trees sprayed with flotation sulfur. This difference in numbers of fruits borne was apparently attributable both to differences in numbers of fruit buds formed and to differences in fruit set. Fruit bud formation was conspicuously heavier in 1943 on the trees sprayed with flotation sulfur. There was no difference in fruit size or finish for the two treatments.

The reduction in carbon dioxide assimilation resulting from the application of lime-sulfur seems to be the fundamental factor underlying differences in fruit set and bud formation. With varieties and in situations where fruit bud formation or fruit set is unsatisfactory, better fruiting and yields can be reasonably anticipated where a milder fungicide such as flotation sulfur is utilized instead of liquid lime-sulfur.

The investigations reported here have dealt only with secondary effects resulting from the use of two fungicides, and not with the primary consideration of apple scab control. Excellent scab control was obtained all seasons with each material, however. Nevertheless there are situations which require that greater weight be given to the maximum fungicidal effectiveness of lime-sulfur than to the minimum injurious effects resulting from the use of an elemental sulfur such as flotation sulfur, when selecting a fungicide for use on apples early in the growing season.

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